

GEOLOGIC SUMMARY INTRODUCTION

The geology of the Poverty Bay 7.5' quadrangle expresses much of the broad range of Quaternary environments and deposits found throughout the central Puget Lowland. The topography is dominated by an extensive upland plain, mantled by a thin layer of glacial till deposited about 17,000 (14,000 radiocarbon) years ago during the last occupation of the Puget Lowland by a great

continental ice sheet. Scattered across this upland surface are the terrace and channel deposits of rivers that issued from the snout of the retreating ice sheet as it withdrew to Beneath these ice-sheet deposits is a complex sequence of older unconsolidated sediments that extends far below sea level across most of the quadrangle. These older sediments are exposed only where modern erosion has sliced through the younger glacial deposits—notably by the Green River, lying a few kilometers east of the east map boundary, and by wave erosion along Puget Sound to the west and southwest. In these areas, the sequences of exposed deposits display both similarities and differences. The older sediments are very compact, having been weighted down by one or more glacial advances subsequent to their deposition. Many are also cemented by iron oxides and hydroxides, a consequence of the many tens or hundreds of thousands of years of weathering that they have experienced. Excellent but widely scattered exposures of this older Pleistocene sequence are displayed in the coastal bluffs of the quadrangle and in active and recently

abandoned quarries. The quadrangle also is located at the center of the intensively developing urban core of the Puget Lowland region. It includes the northeastern part of the city of Tacoma, the third largest municipality in Washington State, and all or part of the cities of Federal Way, Auburn, Kent, Pacific, Algona, Milton, and Fife. Interstate 5, the main north-south highway through the Pacific Northwest, traverses the length of the quadrangle. Increasing population and a strong transportation network have fostered urban and suburban development in almost every part of the quadrangle. This development, in turn, is causing some of

the most rapid geomorphic changes to occur since the wastage of the ice sheet. PREVIOUS MAPPING This edition of the Poverty Bay 7.5' quadrangle relies heavily on the original mapping by Waldron (1961). Map data from that earlier work are used with little modification in the southeastern part of the quadrangle, where excellent exposures once visible in the 1950's are now largely overgrown. Across most of the rest of the map area, there has been a dramatic increase in new exposures caused by development activity, and so many geologic contacts and lithologic descriptions have been revised accordingly. Inderstanding of the stratigraphic framework of Puget Lowland glaciations, improved since Waldron's original (1961) work, has also modified both regional and local

Revised mapping by Booth began sporadically in 1986

interpretations of pre-last-glaciation deposits.

that continue farther west and south (Troost, 1999; Borden

ACKNOWLEDGMENTS (USGS) collected and analyzed the paleomagnetic samples.

STRATIGRAPHY AND HISTORY The east-central Puget Lowland is underlain by Eocene to Miocene volcanic and sedimentary rocks (Yount and Gower, 1991; Tabor and others, 2000). In the Poverty Bay 7.5' quadrangle, these rocks are not exposed at the ground surface; the nearest surface exposures are about 10 km north in the Des Moines 7.5' quadrangle (Booth and Waldron, 2004). From very limited borehole data, this Tertiary

and again in earnest in 1988-89, during preparation of watershed planning documents for the central and western parts of the quadrangle on behalf of King County. Additional field work occurred during 1995-99, primarily along the coastal exposures of Puget Sound and in the ravines draining east into the Green River valley. Troost began detailed investigation of the exposures along the Hylebos Waterway in 1995 as part of stratigraphic studies

and Troost, 2001). Particular acknowledgments are due our colleagues who have shared geologic data, insights, and interpretations throughout the current period of additional mapping: Richard Borden, Ray Wells and Ralph Haugerud (USGS); Timothy Walsh and Patrick Pringle (Washington State Department of Natural Resources); and Richard Stewart and Eric Cheney (University of Washington). Jon Hagstrum

east wall of the Puyallup River valley, about 20 km southeast of the quadrangle. Continued study over the last three decades, however, has suggested that the sequence of older sediments is more complex than originally recognized. This sequence of older sediments records the complex interfingering of two unrelated but overlapping geologic phenomena—glacial advances from British Columbia and

bedrock lies between 400 and 600 m below the ground surface in the map area (Jones, 1996).

Ice Occupation of the Quadrangle Stratigraphic Framework Multiple invasions of glacial ice into the Puget Lowland have left a discontinuous record of Pleistocene glacial and interglacial periods. The ice was part of the Cordilleran ice sheet of northwestern North America, which originated to the north in the mountains of British Columbia. During each successive glaciation, the ice sheet advanced into the lowland as a broad tongue, first called the Puget lobe by The coastal and valley-wall bluffs of the Poverty Bay quadrangle locally display very good exposures of glacial and nonglacial deposits, but their interpretation has been enigmatic to geologists for 100 years (for example, Willis and Smith, 1899). The beach-cliff and valley-wall deposits in the map area were subdivided by Waldron (1961) into older glacial ("Salmon Springs" and "Stuck") units and an intervening nonglacial ("Puyallup") unit, by analogy to deposits described in detail by Crandell (1963) along the

volcanic eruptions from Mount Rainier, about 70 kilometers

CORRELATION OF MAP UNITS NONGLACIAL DEPOSITS m (af Qw Qb Qls Qmw Qf Qal YOUNGER GLACIAL DEPOSITS OLDER GLACIAL AND NONGLACIAL DEPOSITS ·······18 ka* ······70 ka* * Dates correspond to boundaries of the Olympia nonglacial interval (Booth and others, 2004) ** Age of boundary from Sarna-Wojcicki and others (2000) Contact ——···· Fault—Dotted where concealed

Strike and dip of beds Inclined Horizontal ----- Pre-Vashon till—Mapped within units Qpof. Qpog_c and Qpog_f where exposed on valley walls or coastal bluffs ×-×-×- Volcanic ash bed Paleomagnetic sample locality T7012 Reversed magnetization Beta-95340 14C age locality—See table 1 for ages

Infrared-stimulated luminescence (IRSL) ago

sparse vegetation.

respectively, each display distinctive characteristics:

complex and now rather poorly exposed sequence of glacial

and nonglacial sediment is present. Once mined extensively

offered by the several roads that traverse this escarpment

and by the several stream channels that have carved ravines

North of Peasley Canyon, exposures are largely

restricted to small gullies, many of which largely are choked

with landslides and other mass-wastage debris that, although

too small to show at map scale, nonetheless obscure

stratigraphic relations. Southeast of Lake Fenwick, however,

Waldron (1961) reported an outcrop displaying about 10 m

of mudflow-alluvial complex beneath Vashon Drift, exposed

in a small ravine; this complex (mapped here as unit Qpfn)

consisted of interbedded fine- to medium-grained volcanic

sand, locally containing pumice fragments and clay lenses,

South of Peasley Canyon, we have mapped a relatively

continuous contact at about 60 m (200 feet) altitude between

the following two sequences: (1) underlying fluvial

sediments, presumed to be of nonglacial origin (mapped

here as Qpon) on the basis of the absence of northern-

provenance lithologies in the deposits, as well as the widely

scattered presence of pumice-rich beds, the purplish color of

many of the beds, and the local gravel imbrication showing

flow to the northwest; and (2) overlying deposits that,

owing to poor exposures and because they have a more

ambiguous origin and may possibly include more than a

single glacial or nonglacial interval, we have elected to map

as unit Qpf. At the mouth of Peasley Canyon, Westgate and

others (1987) identified an exposure of the 1-Ma Lake

Tapps tephra of Crandell (1963) in the underlying

sediments; despite its probable nonglacial origin, it is

mapped here within the undivided unit Qr (instead of Qrn)

and fine-grained slurry-like mudflows.

DESCRIPTION OF MAP UNITS NONGLACIAL DEPOSITS Modified land (Holocene)—Sand and gravel as fill, as well as extensively graded natural deposits. Includes extensive fill surrounding Hylebos Waterway in southwest corner of map, in part gradational with adjacent river alluvium, and voluminous cut-and-fill highway interchanges for Interstate 5. Where topographic base map (ca. 1961) does not reflect subsequent human modification, original (unmodified) deposit has been mapped where information is available. Locally subdivided into: **Artificial fill**—Gravel, sand, silt, concrete, and other materials, placed as direct result of human

activity. Shown where greater than about 3 m (10 Wetland deposits (Holocene)—Peat and alluvium, poorly drained and intermittently wet. Grades into unit Qal. Compiled from King County (1983); areas shown are not a complete inventory of such Beach deposits (Holocene)—Well-sorted sand, pebbles, silt, and shells deposited or reworked by wave action. Includes upper-beach deposits above mean high-water line, extensive tideflats below

mean high-water line, and local thin veneer of modern beach sediment that overlies older deposits. At stream mouths, grades into unit Qal Landslide deposits (Holocene)—Diamict of broken to internally coherent surficial deposits that have been transported downslope en masse by gravity. Numerous unmapped areas of both landslide and related mass-wastage along coastal bluffs of Puget Sound, as well as ravines draining east to Green River, particularly where coarse deposits (units Qva and Qpog) overlie fine deposits (units Qm and Mass-wastage deposits (Holocene)—

Undifferentiated colluvium, soil, and landslide debris having indistinct morphology. Numerous unmapped areas of mass-wastage deposits are present elsewhere in quadrangle along coastal bluffs of Puget Sound and in ravines draining eastward to the Green River valley. Deposits, both mapped and unmapped, include abundant discrete landslides that are meters to tens of meters in lateral extent Alluvial fan deposits (Holocene)—Boulders, cobbles,

Alluvium (Holocene)—Moderately well sorted deposits of cobble gravel, pebbly sand, and sandy silt along floodplain of Green River YOUNGER GLACIAL DEPOSITS Deposits of the Vashon stade of Fraser glaciation of Armstrong and others (1965) (Pleistocene)— **Recessional outwash deposits**—Stratified sand and gravel, moderately well sorted to well sorted; less common silty sand and silt. Generally lightly oxidized. Deposited in broad anastomosing outwash channels that carried south-draining glacial meltwater away from the ice margin during ice retreat. Deposits less than about 1 m thick not shown on map. Locally subdivided into: Recessional lacustrine deposits—Very finegrained sand, silt, and clay deposited in small lakes during ice recession Recessional coarse-grained lacustrine deposits—Composed of coarse-grained sand, forming crude terraces as high as about 30 m (100 ft) above Poverty Bay. Probably subaqueous deposits of streams flowing into one of icedammed lakes that filled trough of Puget Sound late in ice recession **Ice-contact deposits**—Deposits that are similar in texture to unit Qvr but commonly are less well sorted and have silt-rich matrix. Contains lenses and pods of till. Most voluminous ice-contact deposits flank valley of Green River in northern part of quadrangle, forming kame terrace built

streams emerge from confining valleys and

reduced gradients cause sediment loads to be

against late-recessional ice tongue in Green River valley. Locally subdivided into: Eskers—Sinuous ridges of glaciofluvial sand and **Till**—Compact diamict containing subrounded to well-rounded clasts in massive, silt- or sand-rich matrix. Glacially transported and deposited. Generally a few meters to a few tens of meters thick, forming undulatory surface. Also found sporadically within areas mapped as unit Qvi Advance outwash deposits—Well-bedded sand and less common gravel deposited subaqueously or by streams and rivers in front of advancing ice sheet. Almost devoid of silt or clay, except near base of unit. Generally unoxidized and commonly very gravel, and sand deposited in lobate form where

Deposits of pre-Fraser glaciation age (**Pleistocene**)—Weakly to moderately oxidized sand and gravel, lacustrine sediments containing local peat layers, and moderately to strongly oxidized diamict composed of silty matrix and rounded gravel clasts. Includes deposits of both glacial and nonglacial origin. Locally mapped Coarse-grained deposits—Sand and gravel Nonglacial deposits—Abundant organic debris or pumice indicates nonglacial origin Olympia beds of Minard and Booth (1988) (**Pleistocene**)—As much as 15 m of andesitic and pumiceous sand and lahar deposits, having paleosol developed on upper surface; locally overlain with as much as 1 m of peat and tephra. Assigned to the Olympia nonglacial interval of Mullineaux and others (1965) on the basis of finite radiocarbon dates on peat of 27,530±390, $32,040\pm690$, and $36,650\pm72$ yr B.P. (samples ISGS-3301, Beta-80937, and Beta-87981) Deposits of Pre-Olympia age (Pleistocene)— **Fine-grained deposits**—Silt at north edge of map; underlies glacial deposits of pre-Olympia age on adjacent Des Moines 7.5' quadrangle Glacial deposits—Weakly to strongly oxidized silt, sand, and gravel of glacial origin as determined by clast provenance. Underlies all Vashon-age deposits and so also must be of pre-

OLDER GLACIAL AND NONGLACIAL

Olympia age. Locally mapped as: Coarse-grained deposits—Sand and gravel Fine-grained deposits—Silt and clay pre-Till deposits—Till or other diamict pre-Nonglacial deposits-Silt, fine- to mediumgrained sand and gravel, pumice, and mudflow, exposed low on valley walls of the Reversely magnetized deposits (Pleistocene)—Silt fine- to medium-grained sand; volcanic ash,

pumice, and mudflows; and compact oxidized

till and stratified sand and gravel. Mapped as

reversely magnetized where deposits of the Lake

Tapps tephra of Crandell (1963) as dated by

hydrologic effects.

well exposed.

340 Upland surface Vashon Drift Till overlying crossbedded to laminated to massive sand having northern Cascades lithologies 0.0000000000 0.0000000000 200 Olympia beds Predominantly volcanic lithologies; dated peat and paleosol overlying tephra and diatomaceous 0.000000000 layer; mixed-lithology gravel overlying peat layer 14C date (peat): 32,040±690 yr B.P. (sample Beta-80937): 27.530+390 vr B.P. (sample ISGS-3301) 00000000000 ⁴C date (paleosol in interior part of quarry): 41,710 yr B.P. (sample Beta-86842) 0 000000 Pre-Olympia drift Highly oxidized gravel having northern Cascades lithologies; intense argillic alteration and oxidation at top Pre-Olympia nonglacial deposits Sand having predominantly volcanic lithologies reversely magnetized; 4 tephra layers, zircon fission-track date of 1.1±0.1 Ma (R. Stewart written commun., 1999) cl si fs ms cs gr Predominant grain size cl clay fs fine sand

Figure 1. Composite Measured Section, Hylebos Waterway (lat 47.273° N, long 122.373° W), showing elevation plotted against grain size. See table 1 for ¹⁴C ages.

ms medium sand

cs coarse sand

gr gravel

to the southeast—that are superimposed on the less dramatic, but still ongoing, westward transport of riverborne sediment from the Cascade Range. fundamental importance to interpreting this sequence. In many parts of the Puget Lowland, this can be accomplished on the basis of rock and mineral assemblages that are related to different source areas. Three major source areas have contributed rock clasts and mineral grains to the lowland deposits: Northern provenance, characterized by igneous and

high-grade metamorphic rocks and minerals, which are derived from the North Cascades and Coast Range of British Columbia and which require ice-sheet transport during glacial periods Central Cascade provenance, characterized by the volcanic (primarily) and igneous rocks and minerals of Tertiary age, which compose most of the Cascade Range east and southeast of the quadrangle and which require only river transport for their appearance here; and Mount Rainier provenance, characterized by hypersthene andesite and pyroclastic rocks from Mount Rainier, which have been brought into the quadrangle either by normal river transport or by catastrophic volcanic mudflows (lahars). Local alpine glaciers also may have contributed minor amounts of sediment of the Central Cascade and Mount Rainier provenances into the quadrangle, but the possible influence of these glaciers cannot be recognized on the basis of source area alone The naming and regional correlation of the individual glacial advances in the Puget Lowland has had a long history, one that is still evolving. Willis (1898) was first to present evidence for multiple glaciations in the Puget Lowland. More recently, Crandell and others (1958) proposed a sequence of four glaciations, separated by nonglacial intervals, on the basis of stratigraphic sequences in the southern Puget Lowland, about 20 km southeast of the quadrangle. Farther north, Easterbrook and others (1967) named and described deposits of three glaciations and their intervening nonglacial periods. Dating of these "southern" and "northern" stratigraphic sequences (Easterbrook and others, 1981; Westgate and others, 1987), however, suggests little correlation between them. In its type area eastsoutheast of the Poverty Bay quadrangle, the Salmon Springs Drift (Crandell and others, 1958), which immediately underlies deposits of the most recent ice-sheet advance (the Vashon Drift), has been shown to be older than

774,000 yr old, on the basis of reversely magnetized

sediment present within the unit (Easterbrook and others,

1981). In contrast, the glacial deposits of pre-Vashon age in

the north-central Puget Lowland (Possession and Double

Bluff Drifts) have been dated between 80,000 and 250,000

yr old using amino-acid racemization and paleomagnetic methods (Blunt and others, 1987). Deposits Predating the Vashon Stade of the Fraser Glaciation Various kinds of waterlain sediments are exposed beneath deposits of the most recent ice-sheet advance (which occurred during the Vashon stade of the Fraser glaciation of Armstrong and others, 1965), mainly along the Puget Sound coastline and the Green River valley wall. The thickness of individual layers ranges from a few meters to about 10 m. The sediments are subdivided primarily on the basis of age, but because dating techniques are relatively imprecise for these sediments, we can specify only coarse stratigraphic divisions at this time. In the Poverty Bay quadrangle we recognize the following three localities of reversely magnetized sediment: (1) along the west wall of the Green River valley in the southeastern quadrant of the map, where Westgate and others (1987) reported two localities of the 1-Ma Lake Tapps tephra of Crandell (1963) (mapped here within unit Qr); (2) on the coast of Puget Sound near Adelaide (sample T7310), where it is interbedded with volcanic sediment 1.1-Ma tephra (sample S-5; R. Stewart, University of Washington, written comm., 1999) (also mapped here within unit Qrn). In addition, three other localities of reversely magnetized sediments have been identified along the Puget Sound coastline, just north of the quadrangle boundary (Booth and Waldron, 2004). Where paleomagnetic determinations are absent, pre-Fraser deposits (Qpf and Qpo) are subdivided on the map, if at all, only on the basis of their presumed depositional environments and not by age. Exposures are not everywhere adequate, however, to make this determination

with confidence. Where organic material or volcanic

sediment is abundant, we have recognized a likely

nonglacial origin (units Qpfn and Qpon). Those deposits

about 43 m (140 feet) altitude in sec. 5, T. 21 N., R. 4 E., presumed to be glacial in origin. Because all pre-Fraser-age and it descends below sea level altogether both north into Saltwater State Park and southwest to near the west edge of glacial periods also precede the Olympia nonglacial the quadrangle. Exposed above this unit is a thicker unit of interval, these deposits are designated as pre-Olympia (unit oxidized sand and gravel that contains local lenses of finer grained sand and silt towards the west and that has gravel Within the pre-Fraser and pre-Olympia deposits, the lithologies consistent with a northern (glacial) provenance; texture is identified on the basis of grain size: coarse, predominantly gravel and sand (units Qpfc or Qpogc); or fine, one till layer is well exposed in the creek at Redondo but is less continuously exposed on the hillsides north and west at predominantly silt and clay, (units Qpo_f and Qpon_f). Areas of concordant altitudes. The oxidized sand and gravel deposit glacial till that can be shown at map scale are delineated as unit Qpog_t. Along the Green River valley wall, many of the generally can be distinguished from the overlying advance coarse-grained pre-Fraser-age deposits are volcanic-rich and outwash deposits of Vashon age on the basis of its greater probably reflect a Pleistocene record of mudflows during oxidation and its overall degree of relative weathering, although in any given exposure these criteria may not be nonglacial intervals from the vicinity of the modern Mount conclusive. Along much of the coast, however, Vashon-age We make no effort to assign stratigraphic names to advance outwash deposits are missing (either eroded or subdivisions of the pre-Fraser deposits because absolute age never deposited), and so Vashon-age till (unit Qvt) overlies control is limited at present, and so the likelihood of the older material directly Just north of Redondo a till that appears to underlie the spurious correlations is high. Layers or lenses of diamict of laminated silt and clay crops out at sea level. Although the presumed glacial origin, whose deposition predates the Vashon stade but are too thin to show at map scale, are

till may be a low draping of Vashon-age sediment, the shown with a triangle-dash line within areas of units Qpo overall topography suggests that the Vashon-age deposits lie about 100 m higher on the slope. Insofar as this till lies in and Qpog. Their absence elsewhere on the map reflects not the axis of a broad anticline, defined by bedding in the only the likely discontinuity of these deposits but also the typically poor exposures across the map area, even under overlying fine sediment, it appears to represent deposition of a third glacial advance that preceded both the Vashon-age relatively favorable conditions of steep topography and ice advance and the glacial interval represented by the oxidized gravel and sand outwash. Beneath that till, an Details of the pre-Fraser-age deposits vary across the quadrangle. The following three subregions, in the eastern, infrared-stimulated luminescence (IRSL) age of 203±10 ka northwestern, and southwestern parts of the map area, was obtained on fine-grained sand (sample WA-7; Mahan and others, 2003), suggesting that the overlying glacial Green River Valley Wall—Along the western wall of the deposits correlate to the Double Bluff and Possession drifts Green River, near the east edge of the quadrangle, a of Easterbrook and others (1967). Southwest of Redondo another till crops out near sea level. It is variously clast rich to clast poor, is faintly for sand and gravel, most of this 100-m-high face is now layered, and is at least 6 m thick. The till descends from the heavily vegetated, and only widely scattered exposures are east, concordant with the 12° westerly dip of older strata in

this area, and is truncated abruptly within a large coastal

Beyond the landslide to the west, till is not exposed again as far as the edge of the map area. In place of till, beds exposed on the coastal bluff west of the landslide are predominantly lacustrine deposits of gray and purplish-gray volcanic sand of Mount Rainier provenance, as well as grayto-brown stratified silt and clayey silt. These deposits also include some thin gravel lenses, woody layers, and organic silt beds; the sand is quite pumiceous locally. About 0.5 km west of the landslide, the paleomagnetization of these sediments is reversed (sample T7310), and so the deposit is presumably older than 774,000 years (unit Qrn). Hylebos Waterway Bluff—Only along the bluff northeast of the Hylebos Waterway (see measured section, fig. 1) does absolute age control permit specific assignments for at least part of the pre-Fraser-age deposits. Here, three finite radiocarbon dates (samples ISGS-3301, Beta-80937, and Beta-87981; see table 1) specify interbedded sand, lahar deposits, tephra, and organic material as belonging to the Olympia nonglacial interval (Mullineaux and others, 1965; Armstrong and others, 1965). These deposits (Qob), as much as 5 m thick, directly underlie Vashon-age advance outwash deposits (Qva) and directly overlie oxidized gravel and sand (Qpog_c). Where these deposits are absent along this bluff, the contact between the Vashon-age and the pre-Fraser-age deposits remains easily identified on the basis of an abrupt oxidation change and an only gradually varying altitude. One IRSL date of 232±18 ka has been collected from unit Qpog_c in this immediate area (sample WA-6; Mahan and Tephra is present at two other stratigraphic horizons: two layers within unit Qob, near the east edge of sec. 36, T.

because its lateral continuity and stratigraphic relations are largely obscured by vegetation and by modified land resulting from the highway through Peasley Canyon. 21 N., R. 3 E., and four layers within unit Qrn, at an At the base of the Green River valley wall in the elevation of about 10 m (30 ft), immediately north and southeast corner of the quadrangle, a thin discontinuous northwest of the center of sec. 36, T. 21 N., R. 3 E., which (mapped here within unit Qrn); and (3) along the Hylebos band of older glacial deposits was mapped by Waldron have been fission-track dated at 1.1 Ma (R. Stewart, Waterway (sample T7012), where it is interbedded with a (1961): north of Algona, Waldron defined it as an University of Washington, written comm., 1999). erentiated glacial deposit; south of Algona, he assigned it to his (oldest) "Stuck glaciation." Since 1961 from recent extensive quarrying, which has rendered most of these exposures have disappeared beneath slide obsolete the topographic base map in this area. We have debris and vegetation; what remains are isolated outcrops of elected to plot *contacts* in accord with their presumed map pattern, using the existing contour lines (in other words, sand, pebbly silt, and diamict of both glacial and nonglacial origin, including a valley-wall exposure of the 1-Ma Lake how the contacts would appear on the ground surface as Tapps tephra of Crandell (1963) at Algona, identified by contoured), and *samples* within the stratigraphic unit in Westgate and others (1987). We have included all of these which they were collected but otherwise as close to their deposits in unit Qr because the exposures necessary to depict actual latitude and longitude location as possible (but without regard to the contoured elevation). The locations a more precise discrimination at map scale are absent. and altitudes reported in table 1 reflect actual sample Poverty Bay Bluff—Along the shores of Poverty Bay, in the northwestern part of the quadrangle, the sequence of locations, however, as of the date of collection. pre-Fraser-age deposits appears to be regular, and the Age Determinations in and near the Poverty Bay Quadrangle—Few absolute age determinations are available outcrop pattern at sea level is controlled by the undulating

> **Table 1.** ¹⁴C ages in the Poverty Bay quadrangle Age, in ¹⁴C yr Age, in solar yr Location Collected by Reference Beta-95340 SW¹/₄SW¹/₄ sec. 25, 59 (190) >53,480 Borden and Troos (limiting 50 (160) 27,530±390 28,350-26,750 Borden and Troost Borden and Troos 50 (160) 32,040±690 33,650-30750 Beta-89875 NW¼SW¼ sec. 31, T. 21 N., R. 4 E. 40 (140) Borden and Troost Beta-86842 SW¹/₄SW¹/₄ sec. 25, T. 21 N., R. 3 E. Borden and Troost Beta-87981 SE¹/₄NE¹/₂ sec. 36, T. 21 N., R. 3 E. 36,650±720 38,250-35250 40 (140) ¹ Present is considered to be 1950 A.D. ² Calibrated radiocarbon age (2-sigma range) (Stuiver and Reimer, 1993; Bronk Ramsey, 1994)

three tills near the base of the north Cedar River valley sidewall (SW¹/₄NW¹/₄, sec. 24, T. 23 N., R. 5 E.) is normally magnetized (D. Easterbrook, written commun., in Booth, 1995). Thus, the entire exposed section of Quaternary sediments in that area is probably post-Salmon Springs in age. In the Des Moines 7.5' quadrangle (Booth and Waldron, 2004), reversely magnetized deposits are present within 2 km north of the Poverty Bay quadrangle, and they are inferred to extend into the northwest corner of the Poverty Bay quadrangle on the basis of textural and structural continuity. Along the valley walls of both the Green River and the Puyallup River within and southeast of the Poverty Bay quadrangle, Easterbrook and others (1988) reported a suite of reversely magnetized samples in and near the type sections of the Orting, Alderton, Stuck, Puyallup, and Salmon Springs glacial and nonglacial deposits (Crandell, 1963). These sites include a locality of the Lake Tapps tephra of Crandell (1963) mapped by Westgate and others (1987) in the southeast corner of the Poverty Bay Within the map area, radiocarbon dates (table 1) have

been obtained at several localities along the north shore of the Hylebos Waterway Correlation of Pre-Fraser-Age Deposits—Although the seemingly regular sequence of glacial and nonglacial deposits in the three subregions of the quadrangle invites broader correlation, only a few such connections appear warranted using presently available data. One set of correlative sites includes the dated 1.1-Ma locality of unit Qrn along the Hylebos Waterway, which is within the same time range as previously dated deposits of the Lake Tapps tephra of Crandell (1963) to the southeast (Westgate and others, 1987) along the southern half of the east edge of the map area and at the Salmon Springs type locality. Another correlative site in this set has been identified using fissiontrack dating just west of the town of Sumner, immediately south of the southeast corner of the quadrangle (Troost,

A second, more speculative set of correlative sites involves the well-exposed and laterally extensive pre-Fraser-age oxidized glacial outwash deposit of the Hylebos Waterway (mapped in unit Qpfg_c). This deposit not only is present within the map area but also can be traced readily and continuously to the northwest and southeast beyond the quadrangle boundaries. It is plausibly correlative with mapped areas of Qpfg_c above the shores of Poverty Bay, about 8 km north of the Hylebos Waterway, on the basis of its texture, weathering, and stratigraphic position. Its correlation is less certain, however, with deposits mapped as unit Qpf along the Green River valley wall and in Peasley Canyon; these eastern deposits are more heterogeneous and may in fact predate or bracket (in age) what we interpret to be a single glacial interval represented by the western

Deposits of the Vashon Stade of the Fraser Glaciation

In contrast to uncertainties in age and stratigraphic

assignment of older Pleistocene glacial and nonglacial

deposits, the deposits at or near the land surface are readily

assigned to the youngest regionally recognized glacial

advance, the Vashon stade of the Fraser glaciation

wide as it passes south out of the map area in the vicinity of

large wetland in sec. 28, T. 22 N., R. 4 E.). Most of the (Armstrong and others, 1965). During this time an ice sheet outwash in the map area lies at higher altitudes, presumably progressively advanced along the axis of the Puget Lowland reflecting discharge issuing from the retreating upland ice from the north (Clague, 1981), reaching its maximum extent about 17,000 (14,000 radiocarbon) yr B.P. and covering the Puget Lowland to a maximum depth of about 1,500 m (Booth, 1987; Porter and Swanson, 1998). Deposits of the Vashon stade have a variety of textural characteristics and topographic expressions, owing to rapidly changing depositional environments caused by the advance and retreat of the ice sheet. As the ice first advanced, it blocked northward lowland drainage out the Strait of Juan de Fuca, which presently connects Puget Sound with the Pacific Ocean. In the impounded lakes that formed during the laminated silt and clay were deposited. This material has been mapped to the north and east as either "Lawton Clay" (see, for example, Waldron and others, 1962) or transitional beds" (see, for example, Minard and Booth, 1988; Yount and others, 1993). The latter term reflects the possibility that the unit may include deposits of pre-Vashon lowland lakes in addition to those formed in the subsequent ice-dammed environment. Although this depositional environment probably existed in the Poverty Bay quadrangle during both pre- and early-glacial time, no mappable deposits correlative with these units have been recognized. The initiation of the Vashon stade is marked by coarse advance outwash deposits (Qva), which were deposited by streams flowing from the advancing ice sheet. Deposits at least a few tens of meters thick (and locally as thick as 100 meters) underlie the broad upland areas in the central part of the quadrangle. They inundated the pre-Vashon topography Kames and kame-terrace deposits, jointly mapped within of the lowland and resulted in a south-sloping surface at an unit Qvi, are found in the southern and northeastern parts of elevation of about 120 m (400 ft) in the area (Booth, 1994). The most extensive outcrops of advance outwash deposits the map area. Kames are isolated mounds or hummocks of irregular drift deposited in ice-walled depressions; they are in the southern part of the quadrangle, where as much as commonly are associated with kettles, which are depressions about 50 m of sand and gravel is exposed between the or lakes scattered across recessional outwash surfaces that Vashon till and the Olympia beds or older outwash. Most mark the location of melted-out ice blocks. Most kames exposures consist of light-gray to very-light-brown sand, or sand and pebble- to cobble-sized gravel. The outwash consist of poorly sorted and poorly bedded sand and pebblevaries from poorly to well sorted, and it is typically to cobble-sized gravel, in which foreset bedding and slumped structures are common. Kame-terrace deposits are moderately well to well bedded. composed of glaciofluvial sand and gravel deposited Advance outwash deposits form an important aquifer between a valley wall and either active or stagnant ice. In throughout the Puget Lowland, but this aquifer is particularly significant in the Poverty Bay quadrangle. It is the Poverty Bay quadrangle, the northernmost 3 km of the eastern upland escarpment is mantled by these sediments, highly permeable and supports most of the major production forming the southern end of a much more extensive deposit wells for the cities of Federal Way and Milton (Robinson that marks a late-recessional period of fluvial deposition and Noble, 1992). In the map area its subsurface distribution against an ice tongue in the adjacent Green River valley forms a southward-narrowing and southward-deepening channel, defined in multiple water-supply wells. The The sediments consist mostly of silty sand and pebble- to cobble-sized gravel; locally they include lenses and pods of channel begins just landward of the Poverty Bay coastline, till, as well as lenses and beds of sand, silt, and clay. at about elevation 60 m (200 ft), and traverses more than 5 km from Redondo south past the boundaries of the quadrangle. The channel narrows to only a few kilometers

are too well drained by the free face above the Hylebos Waterway to provide much opportunity for water supply. As ice covered the region, lodgment till (Qvt) was deposited by the melt-out of debris at the base of the glacier. This heterogeneous, compact sediment blankets the area to depths of, at most, a few tens of meters; the ground surface underlain by this deposit is locally fluted with elongated hills that have a weak but uniform north-south orientation across the quadrangle. Where present at the surface, the till provides a low-permeability cover to underlying aquifers, reducing recharge but also offering protection from surface contaminants. Where it is overlain by more permeable sediment, the till commonly is still

present at depth, and so it slows groundwater migration and The matrix of the till differs from place to place in relative proportions of clay, silt, and sand, but mostly it is made up of silty sand to sandy silt. In many places, the till is substratified and contains lenses of sand, gravel, and silt. Larger rock fragments, which are scattered throughout the till, are mostly pebble to cobble size; boulders more than 1 m in diameter are present but uncommon; rare boulders more than 4 m in diameter have been observed. Unoxidized till is light gray and compact; where oxidized, the till is light yellowish gray and generally is loosely consolidated. Although a weak brown soil is developed on the till, oxidation rarely extends more than about one meter into the

Shortly after 17,000 (14,000 radiocarbon) years ago, the

today at about 75 m (250 ft) elevation (about the level of

both Panther Lake, in sec. 19, T. 21 N., R. 4 E., and the

ice margin, which by that time had advanced south of the city of Olympia, about 70 kilometers south of the bodies (areas of QIs and Qmw that are greater than about 150 quadrangle, began to recede. Recession of the ice margin m in lateral extent) are shown on the map. Colluvium, a few was accompanied by both outwash deposits and ice-dammed centimeters to a few meters thick, covers nearly all the lakes, analogous to those formed during the ice advance. valley walls and slopes. It consists of a mixture of locally Water from the melting ice sheet, and also from the Cascade derived materials, principally loosely consolidated silty Range, drained southward and westward, spilling over high sand and gravel. Small landslides, common in the steep divides that later were abandoned as ice pullback exposed bluffs and slopes, consist of slumps and earth flows caused more low-lying drainage routes farther north. chiefly by surf erosion or by spring sapping. Individual By the time that the area of the Poverty Bay quadrangle slides are generally small; however, the ravines and coastal was uncovered by the retreating ice, proglacial drainage was bluffs are replete with slides. Although too small to show on well established across most of the eastern and southern the map, they can be quite hazardous in populated areas. lowland areas. Water was impounded in a large lake that Steep slopes in fine-grained units (Qpfn or Qrn) overlain by inundated much of the central and southern Puget Lowland coarse-grained units (Qpog_c or Qva) are particularly because northward drainage was blocked by more than one susceptible to failure because of groundwater perching. This thousand meters of glacial ice that still filled the Strait of condition is found in many of the steeply sloping parts of Juan de Fuca. This water body, Glacial Lake Russell, drained out through the Black Hills, just south of Olympia, Six major landslides are delineated on the map, all adjacent to the bluffs above Puget Sound. The most active into the Chehalis River many tens of kilometers to the south of the quadrangle (Thorson, 1980). Although the elevation slide, the "Woodmont slide," reaches sea level in sec. 32, T. of the Black Hills spillway was only about 40 m high, the 21 N., R. 4 E.; movement of the southern part of this slide present-day elevation of the ancient shoreline of Glacial in early 1997 rendered several houses unsafe for occupancy. Lake Russell is now higher because the land surface of the Another historically active slide, the "Buenna slide" in sec. entire Puget Lowland has rebounded since the subsequent 6, T. 21 N., R. 4 E., displays a particularly clear suite of removal of the weight of the ice sheet. More rebound morphologic features: an abrupt unvegetated headscarp, occurred in the north than in the south because the ice was truncated deposits in the bluff below, and a very large and thicker to the north. In the center of the Poverty Bay old fir tree at the center of the downdropped block now quadrangle, the amount of rebound has been about 35 m, standing at an angle of about 10° from vertical. In the midand so the level of Glacial Lake Russell during active 1980's, the upper surface of this downdropped block was deposition of recessional outwash (Qvr) can be recognized proposed as the site of a housing subdivision, a plan

Mount Rainier Mudflows A lower regional lake level, that of Glacial Lake Bretz Mount Rainier has exerted a profound influence on the geology of the quadrangle, even though this active volcano (Waitt and Thorson, 1983), which reflects the first currently does not drain directly into the Green River. postglacial access of Puget Sound drainages to the Strait of Episodic eruptions have triggered massive landslides on the Juan de Fuca, may also be indicated by lacustrine sediments flanks of the mountain, whose debris materials in turn mix (Qvrl) that now fill the lower valley of the west branch of Hylebos Creek, in secs. 29 and 32, T. 21 N., R. 4 E., and with water from the rapidly melting snowfields and glaciers. sec. 5, T. 20 N., R. 4 E. The surface altitude of these The resulting slurry of mixed sediment moves rapidly down one or more of the river valleys that radiate from the lacustrine sediments is concordant with sea level during late recessional time (correcting for subsequent isostatic uplift; mountain, emerging out onto the lowland as a mudflow (or Holocene damming of the valley mouth by the Osceola The Osceola mudflow of Crandell and Waldron (1956) is mudflow (see section below entitled, "Mount Rainier one of the largest recognized volcanic mudflows in the Mudflows;" see also, Dragovich and others, 1994). world. Originally thought to be an alpine till (Willis, 1898), During ice recession, ice-contact sediments (Qvi) were it was later recognized as a lahar deposit from Mount also being deposited in a variety of environments. The Rainier. The lahar flowed down the flanks and tributary oldest of these deposits are eskers (Qvie), which can be valleys of the volcano, spreading mainly northward upon recognized as narrow sinuous ridges traversing the glaciated reaching the Puget Lowland. It entered what is today the uplands and which formed as fluvial sand-and-gravel Green River valley south of Auburn and continued north past the city of Kent, just northeast of the quadrangle. At the fillings of subglacial tunnels of beneath slow-moving or near-stagnant ice. Although subglacial water was time of the eruption about 5,700 years ago, the lahar deposit ubiquitous beneath the Vashon ice sheet (Booth, 1991), the covered an area of at least 330 square kilometers; its Poverty Bay quadrangle is one of the few areas of the Puget average thickness now is about 8 m, and its volume is Lowland where eskers have been mapped. Unfortunately estimated at nearly 4 km³ (Dragovich and others, 1994). The they are rapidly being obliterated by excavation for sand deposit can be recognized because of its groundwaterand gravel, as well as by regrading for the convenience of retarding properties, even at depths of more than 60 m suburban development. Locally, they also are the preferred below the modern ground surface (Dragovich and others, paths for elevated sections of state highways.

The Osceola mudflow is a useful stratigraphic marker in the lower Green River valley. All of the 30-60 m of sediment that overlies the mudflow, which now fills the valley from just east of the quadrangle north and northwest to the modern shore of Puget Sound, have been deposited by river transport in the last 5,700 years. The mouth of the Green-Duwamish River estuary has advanced northward about 50 kilometers during that time, at a rate of about 9 m per year. This rapid advance reflects the dominant sedimentary contribution of the White River, which flowed northward down the (modern) Green River valley during most of the last 5,700 years. This river carried the voluminous products of both normal fluvial transport and volcanic mudflows throughout much of the late Holocene (Dragovich and others, 1994).

The Poverty Bay quadrangle occupies a region of

observed Holocene seismicity. A vertical displacement of

about 7 m has been documented on the Seattle Fault, a

major east-west-striking structure about 25 km north of the

map area (Bucknam and others, 1992). A network of other

faults in the region has been suggested by interpretation of

subsequently abandoned. The other landslides shown on the

map are recognized on the basis of somewhat less obvious

morphologic indicators, particularly the presence of arcuate

Postglacial Processes and Deposits Geologic activity since glaciation has included

containing a suite of sand and (or) gravel lithologies that are structure in these older beds. The oldest consistently in the Poverty Bay quadrangle, but the surrounding area sec. 5, T. 20 N., R. 4 E. (SKCGWAC, 1989). At its deepest widespread slope failure and stream-channel erosion. As a seismic reflection studies in Puget Sound (Johnson and indicative of southward transport from the North Cascades exposed deposit is a laminated silt and clay that has widely provides some relevant data. In the northern part of Maple known extent, in the center of sec. 20, T. 21 N., R. 4 E., the result of the lowered base level caused by drainage of others, 1996). In this quadrangle, faults are visible locally or British Columbia, or that display sedimentary features scattered organic material. Its upper contact lies as high as Valley 7.5' quadrangle began to in the pre-Vashon-age sediments, but their tectonic underlies the upland surface. On the upland surface, soil and (or) poorly exposed to display at map scale. Waldron (1961) reported a set of small northeast-striking normal formation has proceeded slowly but has had profound faults that were partly covered by Vashon-age sediment, in hydrologic consequences. Bare, unweathered till absorbs SE¼ sec. 14, T. 21 N., R. 4 E., but these exposures are no water very slowly; in contrast, the meter or so of soil that longer visible; he also mapped one fault in the SW¼ sec. has developed on the till surface since deglaciation has high infiltration capacities and a large capacity to store and then 35, T. 21 N., R. 4 E., that we include on the current map. slowly release subsurface runoff. This till-derived Other observed displacements and truncations, now best exposed along the steep beach cliffs of Puget Sound, "Alderwood" soil (Snyder and others, 1973) blankets the are most likely the result of Holocene landsliding. majority of the upland plateau. Its hydrologic properties differ so dramatically from its underlying parent material Truncated beds also can be ice-derived or glacially that the compaction or removal of soil during typical urban overridden, raising the possibility of a nontectonic origin or suburban development results in commensurably large More gentle deformation in the pre-Fraser-age sediments is widespread, however, and is almost certainly the result of long-term crustal deformation during the Quaternary Colluvial deposits formed by episodic landslides and period (Booth and others, 2004). rapid soil creep mantle most of the lower slopes of both the coastal bluffs and the Green River valley. Fine-grained

Westgate and others (1987) lie in close

stratigraphic association with these deposits.

Reversely magnetized nonglacial deposits—Silt,

fine- to medium-grained sand, clay, ash, peat,

and mudflow deposits composed of round to

subangular clasts of volcanic rock and pumice in

dense sandy to highly altered fine-grained

matrix. Abundant wood and volcanic debris

Locally mapped as:

demonstrate nonglacial origin

layers and interbeds in the underlying older deposits greatly impede the vertical descent of percolating groundwater, Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B., 1965, Late Pleistocene stratigraphy and which makes the exposed slopes prone to landslides. In chronology in southwestern British Columbia and these environments, wave or river erosion has developed and maintained steep slopes, and emergent groundwater northwestern Washington: Geological Society of promotes continued instability. Several ravines descend America Bulletin, v. 76, p. 321-330. Blunt, D.J., Easterbrook, D.J., and Rutter, N.W., 1987, these slopes, particularly to the east into the Green River valley; where urban development has occurred in the heads Chronology of Pleistocene sediments in the Puget of these ravines, discharge and the commensurate rate of Lowland, Washington: Washington Division of channel incision has increased dramatically, and the Geology and Earth Resources Bulletin 77, p. 321-353. underlying glacial and nonglacial deposits are relatively Booth, D.B., 1987, Timing and processes of deglaciation along the southern margin of the Cordilleran ice sheet, Although landslide deposits, colluvium, and massin Ruddiman, W.F., and Wright, H.E., Jr., eds., North wasting deposits are common, only the largest recognized America and adjacent oceans during the last deglaciation: Boulder, Colorado, Geological Society

> —— 1991, Glacier physics of the Puget lobe, southwest Cordilleran ice sheet: Géographie physique et Quaternaire, v. 45, p. 301-315. ——— 1994, Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation: Geology, v. 22, p. 695-698. ——— 1995, Geologic map of the Maple Valley quadrangle, King County, Washington: U.S.

of America, The Geology of North America, v. K-3, p.

Geological Survey Miscellaneous Field Studies Map MF-2297, scale 1:24,000. Booth, D.B., Troost, K.G., and Hagstrum, J.T., 2004, Deformation of Quaternary strata and its relationship to crustal folds and faults, central Puget Lowland, Washington: Geology, v. 32, p. 505-508. Booth, D.B., and Waldron, H.H., 2004, Geologic map of the Des Moines 7.5' quadrangle, King County, Washington: U.S. Geological Survey Scientific Investigations Map 2855, scale 1:24,000 [available on World Wide Web at http://pubs.usgs.gov/sim/2004/2855/]. Borden, R.K., and Troost, K.G., 2001, Late Pleistocene Stratigraphy in the south-central Puget Lowland, West-Central Pierce County, Washington: Olympia,

Washington State Department of Natural Resources, Report of Investigation 33, 33 p. Bretz, J.H., 1913, Glaciation of the Puget Sound region: Washington Geological Survey Bulletin 8, 244 p. Bronk Ramsey, C., 1994, Analysis of chronological information and radiocarbon calibration: The program OxCal.: Archaeological Computing Newsletter 41, p.

Bucknam, R.C., Hemphill-Haley, E., and Leopold, E.B.,

1992, Abrupt uplift within the past 1700 years at

southern Puget Sound: Science, v. 258, p. 1611-1614.

Clague, J.J., 1981, Late Quaternary geology and geochronology of British Columbia, Part 2: Geological Survey of Canada Paper 80-35, 41 p. Crandell, D.R., 1963, Surficial geology and geomorphology of the Lake Tapps quadrangle, Washington: U.S. Geological Survey Professional Paper 388-A, 84 p. Crandell, D.R., Mullineaux, D.R., and Waldron, H.H. 1958, Pleistocene sequence in the southeastern part of the Puget Sound lowland, Washington: American Journal of Science, v. 256, p. 384-397.

volcanic mudflow of exceptional dimensions from Mount Rainier, Washington: American Journal of Science, v. 254, p. 349-362. ragovich, J.D., Pringle, P.T., and Walsh, T.J., 1994, Extent and geometry of the mid-Holocene Osceola Mudflow in the Puget Lowland: Implications for Holocene sedimentation and paleogeography: Washington Geology, v. 22, p. 3-26. Easterbrook, D.J., Briggs, N.D., Westgate, J.A., and Gorton, M.P., 1981, Age of the Salmon Springs

randell, D.R., and Waldron, H.H., 1956, A Recent

glaciation in Washington: Geology, v. 9, p. 87-93. Easterbrook, D.J., Crandell, D.R., and Leopold, E.B. 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geological Society of America Bulletin, v. 78, p. 13-20. Easterbrook, D.J., Roland, J.L., Carson, R.J., and Naeser, N.D., 1988, Application of paleomagnetism, fission-

track dating, and tephra correlation to Lower Pleistocene sediments in the Puget Lowland, Washington: Geological Society of America Special Paper 227, p. 139-165. ohnson, S.Y., Potter, C.J., Armentrout, J.M., Miller, J.J., Bulletin, v. 108, p. 334-354.

Finn, C., and Weaver, C.S., 1996, The southern Whidbey Island fault: An active structure in the Puget Lowland, Washington: Geological Society of America Jones, M.A., 1996, Thickness of unconsolidated deposits in the Puget Sound Lowland, Washington and British Columbia: U.S. Geological Survey Water-Resources Investigations Report 94-4133, scale 1:455,000. King County, 1983, King County Wetlands: Seattle,

Washington, King County Planning Division, 3

D.B., 2003, Dating sediments older than 100 ka in the stimulated luminescence and thermoluminescence or fine grain deposits [abs.]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 79. Minard, J.M., and Booth, D.B., 1988, Geologic map of the Redmond 7.5' quadrangle, King and Snohomish Counties, Washington: U.S. Geological Survey

Diamicton (lahar deposit)

Miscellaneous Field Studies Map MF-2016, scale Mullineaux, D.R., Waldron, H.H., and Rubin, M., 1965, Stratigraphy and chronology of later interglacial and early Vashon time in the Seattle area, Washington U.S. Geological Survey Bulletin 1194-O, p. O1-O10. Porter, S.C., and Swanson, T.W., 1998, Radiocarbon age constraints on rates of advance and retreat of the Puget lobe of the Cordilleran ice sheet during the las glaciation: Quaternary Research, v. 50, p. 205-213.

Robinson and Noble, 1992, Hydrogeologic analysis of the Federal Way area, Washington: report to Federal Way Water and Sewer District, December 1992, Volume I. Sarna-Wojcicki, A.M., Pringle, M.S., and Wijbrans, J 2000, New ⁴⁰Ar/³⁹Ar age of the Bishop Tuff from multiple sites and sediment rate calibration for the Matuyama-Brunhes boundary: Journal of Geophysica Research, vol. 105, no. B9, p. 21,431-21,443. SKCGWAC (South King County Groundwater Advisor Committee), 1989, South King County groundwater

management plan: Seattle, King County Department of Natural Resources, June 1989, Volume I. Snyder, D.E., Gale, P.S., and Pringle, R.F., 1973, Soil survey of King County area, Washington: U.S Department of Agriculture, Soil Conservation Service

Stuiver, M., and Reimer, P.J., 1993, Extended 14C data base and revised CALIB 3.0 14C Age calibration program: Radiocarbon, 35, p. 215-230. Tabor, R.W., Frizell, V.A., Jr., Booth, D.B., and Waitt R.B., 2000, Geologic map of the Snoqualmie Pass 3 x 60 minute quadrangle, Washington: U.S. Geological Survey Geologic Investigations Series Map I-2538, 1 sheet, scale 1:100,000, 57 p. Thorson, R.M., 1980, Ice sheet glaciation of the Puge

Lowland, Washington, during the Vashon stade Quaternary Research, v. 13, p. 303-321. ———— 1981, Isostatic effects of the last glaciation in the Puget Lowland, Washington: U.S. Geological Survey Open-File Report 81-370, 100 p. Troost, K.G., 1999, The Olympia nonglacial interval in the southcentral Puget Lowland, Washington: Seattle University of Washington, M.S. thesis, 123 p. ——— 2000, The Olympia nonglacial interval in the southcentral Puget Lowland, Washington [abs.]

Geological Society of America Abstracts with Programs, v. 32, no. 6, p. A-72 to A-73. Waitt, R.B., Jr., and Thorson, R.M., 1983, The Cordilleran ice sheet in Washington, Idaho, and Montana, in Porter, S.C., and Wright, H.E., Jr. eds., Late-Quaternary environments of the United States: St Paul, University of Minnesota Press, v. 1, p. 53-70. Waldron, H.H., 1961, Geology of the Poverty Bay quadrangle, Washington: U.S. Geological Survey

Geologic Quadrangle Map GQ-158, scale 1:24,000. Waldron, H.H., Liesch, B.A., Mullineaux, D.R., and Crandell, D.R., 1962, Preliminary geologic map of Seattle and vicinity, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map I 354, scale 1:31,680.

Westgate, J.A., Easterbrook, D.J., Naeser, N.D., and Carson, R.J., 1987, Lake Tapps tephra: an early Pleistocene stratigraphic marker in the Puget Lowland, Washington: Quaternary Research, v. 28, p. 340-355. Willis, B., 1898, Drift phenomena of Puget Sound Geological Society of America Bulletin, v. 9, p. 111-

Willis, B., and Smith, G.O., 1899, Tacoma Folio Washington: U.S. Geological Survey Geological Atlas of the United States, Folio 54, scale 1:125,000. Yount, J.C., and Gower, H.D., 1991, Bedrock geologic map of the Seattle 30' by 60' quadrangle, Washington U.S. Geological Survey Open-File Report 91-147 scale 1:100,000. Yount, J.C., Minard, J.P., and Dembroff, G.R., 1993 Geologic map of surficial deposits in the Seattle 30 by 60' quadrangle, Washington: U.S. Geologica

Survey Open-File Report 93-233, scale 1:100,000.

Any use of trade, firm, or product names in this publication is for descriptive

purposes only and does not imply endorsement by the U.S. Government.

This map was printed on an electronic plotter directly from digital files. Dimensional

calibration may vary between electronic plotters and between X and Y directions or the same plotter, and paper may change size due to atmospheric conditions; herefore, scale and proportions may not be true on plots of this map. For sale by U.S. Geological Survey, Information Services, Box 25286, Federa Center, Denver, CO 80225, 1-888-ASK-USGS

Digital files available on World Wide Web at http://pubs.usgs.gov/sim/2004/285

